A Surgical Navigation and Endoscope Holder Integrated System for Sinus Surgery

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Abstract: In this paper, we developed an integrated system, which consists of an augmented reality-based surgical navigation system (ARSNS) and an endoscope-holder system (EHS) to reduce complications such as blindness, cerebrospinal fluid leak and to solve a constraint on hand movement of surgeons during sinus surgery. The proposed system provides following main functions: warning system, automatic transparency adjustment, magnetic brakes, and counter-balancing mechanism. In addition, the system compensates for AR error which increases with the rotation of the scope cylinder. For the evaluation of ARSNS and EHS, the phantom experiments were performed with surgeons. Through the experiments, surgeons found the proposed system will be effective in performing sinus surgery.

1. Introduction

Sinus surgery is one of the challenging procedures for surgeons since a complex access route to paranasal sinuses is formed in the nose. For less-experienced surgeons, there is a possibility of damaging the orbit and the skull base during the surgery because of its proximity. Therefore, complications, such as blindness, cerebrospinal fluid leak, may be caused [1]. Other problems are as followings: surgeons have to be holding a rigid endoscope during the surgery since sinus surgery is the monitor-based surgery; the surgeons usually use the rigid endoscope with a micro-debrider, a suction, and so on. Consequently, those cause fatigue and a constraint on hand movement.

Surgical navigation system is one of the solutions to reduce the complications by delivering the location of tissues, organs and important bone to surgeons. Its effectiveness has been early verified through the clinical experiments [2]. Recently, an augmented reality (AR) technology has been applied to the surgical navigation. This system reduces the discrepancy between real display and virtual one. However, AR-based surgical navigation system (ARSNS) in the sinus surgery has two problems. First, if augmented objects are displayed on the monitor before an endoscope or a surgical tool is close to the target, they can be an obstacle to seeing inside of nose for surgeons. Second, surgeons frequently change the viewing direction by rotating the scope cylinder of an oblique-viewing endoscope to see ROI during surgery; therefore, camera parameters and camera-tracker relation, which determine the location of the objects to be overlaid, are changed. Consequently, it leads to increasing augmented reality (AR) error.

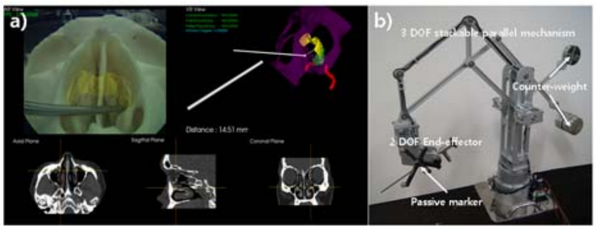

Fig. 1 (a) ARSNS and (b) EHS for sinus surgery

In this study, we developed an integrated system, which consists of ARSNS and endoscope-holder system (EHS) to solve the aforementioned problems. Through the phantom experiments, the accuracy of ARSNS and the effectiveness of EHS were evaluated.

2. Methods

2.1 Configuration of developed ARSNS

For implementing the accurate ARSNS, three main factors are required: image-patient relation, intrinsic parameters, and camera-tracker relation. In our system, each factor was calculated by performing the paired-point registration (PPR), calibrations proposed by [3, 4].

Since the tendency to change parameters according to the rotation of the scope cylinder follows sine or cosine function, AR error was compensated by using the function. For solving the scale, mean, and shift coefficients of the function, the information of camera parameters and camera-tracker relation calculated at the different rotation angles of the scope cylinder is required. The rotation of the scope cylinder was measured through inertia measurement unit (IMU) attached to the scope cylinder.

2.2 Functions of developed ARSNS

Developed ARSNS provides as following main functions: 2-D multi-planar reconstruction (MPR) images (axial, coronal, and sagittal plane), AR view, virtual reality (VR) view, warning system, and automatic transparency adjustment.

The warning system of ARSNS can provide the visual and auditory information. The warning system of ARSNS has three steps. If the reference, which is a pointer or the tip of the endoscope (selectable by user), gets closer to the target, the step increases. According to the steps, the color

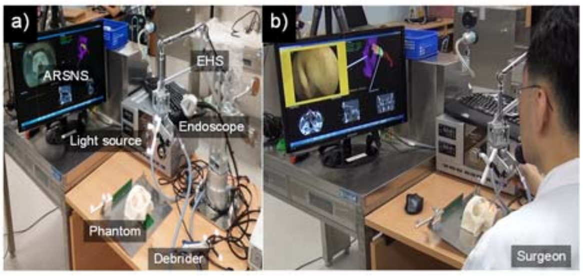

Fig. 2 (a) Experimental setup and (b) phantom experiment

of background (yellow-orange-red) and the frequency of beep sound are changed.

The automatic transparency adjustment was developed to reduce the disturbance of augmented objects. The transparency of augmented objects is changed according to the steps. If the reference gets closer to the target, the step increases from one step (invisibility) to seven step (no transparency) in a similar way to the warning system. Fig. 1a shows developed ARSNS.

2.3 Design of EHS

EHS consists of a 3-DOF stackable parallel mechanism and 2-DOF end-effector as shown in Fig. 1b. The stackable parallel mechanism was designed by combining a five-bar and a couple of parallelograms [5]. This design allows wide workspace and a compact design as compared to prior parallel type counter-balancing mechanisms. Since this mechanism can compensate for gravity load using a counter-weight, surgeons are able to control the end-effector freely in the 3-D space without feeling any gravity load of the holder mechanism. The 2-DOF end-effector was designed for adapting 4 mm endoscope. The system also includes a brake system which can hold the endoscope at any location the surgeons want. By using a tact switch, the operator can move and fix the endoscope without inconvenience. For tracking the endoscope without any intervention, the position sensor marker can be attached on the side or on the front of the end-effector.

2.4 Phantom experiments

Phantom experiments were performed to evaluate the proposed system with surgeons as shown in Fig. 2. Phantom used in the experiments was based on CT of real patient. Before the experiments, sphenoidal sinus, a part of lamina papyracea and skull base, carotid artery, and facial area were segmented. The facial area was used for the confirmation of AR accuracy. Sphenoidal sinus was the target, and the others were important organs or bone not to be damaged. Therefore, warning system were applied to all of segmented objects except for the facial area. By using five anatomical landmarks on the facial area, image-patient registration was performed. After installing endoscope on EHS, calibrations were performed at different rotation angles of the scope cylinder from 0° to 180° with an increment of 30°. The weight increased by installing the endoscope was compensated by using counter-weight. The surgical procedure was simply to access the target using the proposed system. During the procedure, the aforementioned functions of ARSNS and EHS were qualitatively evaluated by surgeons. In addition, the method to compensate for AR error was evaluated by applying the method at 90° of rotation of the scope cylinder.

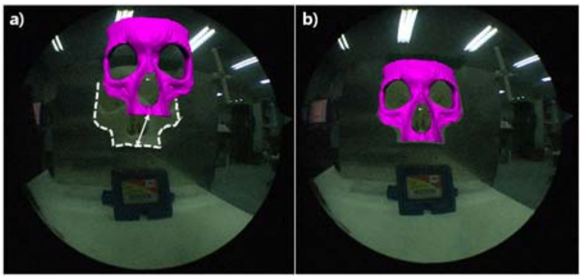

Fig. 3 Augmented objects (a) before and (b) after compensating for AR error at 90° of rotation

3. Results & Discussion

Fig. 3 shows the augmented objects before and after compensating for AR error. The results showed the method significantly compensated for AR error. Through the phantom experiments, surgeons found EHS is fixed at the desired pose without the vibration and the delay when they run the magnetic brakes and the accuracy of ARSNS is acceptable for the sinus surgery despite of the rotation of the scope cylinder. In addition, they found the proposed system will be very effective in performing the sinus surgery.

In the future, we will implement ARSNS by using the information of kinematics of EHS not the passive marker attached to the end-effector of EHS and perform the cadaver experiments.

Acknowledgment

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